TITLE

PER-CHANNEL OPTICAL AMPLIFICATION

USING SATURATION MODE

5 Field of the Invention

The invention is in the field of optical

telecommunications, and more particularly, pertains to

an optical communication system in which individual

channel output power levels are equalized independent

10 of channel wavelength and input power level.

Background of the Invention

In Wavelength Division Multiplexed (WDM) optical links

it is difficult to assure that signals arriving at each

15 channel's photodetector have a power level that is

within the receiver's dynamic range. Even for simple

point-to-point links, flattening filters are used in

the Erbium Doped Fiber Amplifiers (EDFA's), MUX/DEMUX

components' profiles of attenuation vs. wavelength must

be trimmed, and the system must be carefully monitored

to ensure that large inter-channel differences in

5   concatenated connector and splice losses are not

accumulated.

Typically, all WDM channels are amplified in a single

amplifier, with the single amplifier being optimized

10 for gain flatness. However, there are different power

levels in each channel due to differences in

accumulated channel losses at different frequencies.

Variable Optical Attenuators (VOA's) are used in the

respective channels to compensate for the losses. The

15 VOA's require frequent adjustment to maintain required

power levels, and if the power level in a given channel

drops below a minimum level, a transponder is required

in the line to increase the power level to the required

level.

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Thus, there is a need to be able to automatically

readjust the power level on a per-channel basis so that

the photodetector at the optical receiver receives a

signal with an adequate Optical Signal to Noise Ratio
(OSNR) and amplitude to achieve a desired Bit Error
Rate (BER), but not so high a power level that the
optical receiver or the electronics to follow are

5   saturated.

Summary of the Invention

In view of the above, it is an aspect of the invention

10 to adjust the power levels in an optical communication
system on a per-channel basis.

It is another aspect of the invention to adjust the
power levels in an optical communication system on a

15 per-channel basis by including in each channel an
optical amplifier which is operated in the saturation
mode.

It is yet another aspect of the inventions to adjust

20 the power levels in an optical communication system on
a per-channel basis by including in each channel an
optical amplifier, with each such amplifier receiving a

predetermined pump power for operating each such

amplifier in the saturation mode.

It is still another aspect of the invention to connect

5   Optical Line Terminals (OLT's) back-to-back at their

respective pass-through interface channels, with each

channel including an optical amplifier, with each such

amplifier receiving a predetermined pump power for

operating each such amplifier in the saturation mode.

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It is still yet another aspect of the invention to

adjust the power levels in each output channel from a

demultiplexer in a WDM optical communication system on

a per-channel basis, with each such output channel

15   including an optical amplifier, with each such

amplifier receiving a predetermined pump power for

operating each such amplifier in the saturation mode,

with the pump power being provided from either a

predetermined power per-channel pump for each

20   amplifier, or a single shared pump which supplies the

predetermined power to each channel amplifier.

It is a further aspect of the invention to adjust the power levels in each input channel to a multiplexer in a WDM optical communication system on a per-channel basis, with each such input channel including an
5   optical amplifier, with each such amplifier receiving a predetermined pump power for operating each such amplifier in the saturation mode, with the pump power being provided from either a predetermined power per-channel pump for each amplifier, or a single shared
10   pump which supplies the same predetermined power to each channel amplifier.

It is yet another further aspect of the invention to maximize the number of optical hops in an optical ring
15   network by equalizing the output power level in the respective channels due operating the respective channel amplifiers at a predetermined power level by operating the amplifiers in the saturation mode.

20   It is still yet another further aspect of invention to prevent lasing in an optical ring network by operating an amplifier in each channel at a predetermined power level which can't be exceeded, such that one channel

can't rob another channel of power due to the one

channel's wavelength traversing the loop without being

dropped.

5   Brief Description of the Drawings

Fig. 1 is a block diagram of a prior art optical

communication system;

10   Fig. 2 is a block diagram of an optical communication

system according to the present invention;

Fig 3 is a block diagram of a WDM optical communication

system according to the present invention;

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Fig. 4 is a block diagram of one amplifier constituting

an optical channel according to the present invention;

Fig. 5 is a typical graph of power-in versus power-out

20   for the optical amplifier 90 shown in Fig. 4;

Fig. 6 is a block diagram of a plurality of optical

channels whose optical amplifiers receive pumping power

from a shared optical pump;

5 Fig. 7 is a block diagram of how to couple a plurality

of optical pumps to the optical amplifiers of a

plurality of optical channels; and

Fig. 8 is a block diagram of a plurality of optical

10 nodes connected in a ring configuration.

Detailed Description

Fig. 1 is a block diagram of a prior art optical

15 communication system 10 in which an optical facility

signal comprising multiple channels of different

wavelengths is input on a single fiber 12 to an optical

amplifier 14 with flat gain which amplifies the input

signal. The amplified optical facility signal is then

20 demultiplexed by a demultiplexer 16 into its

constituent wavelengths $\lambda 1-\lambda m$, and is applied to an

Optical Cross Connect Switch (OXC) or Optical Add Drop

Multiplex (OADM) 18, and then to a multiplexer 20 which

multiplexes the wavelengths $\lambda 1$-λm to form an optical
facility signal comprising the multiple wavelengths $\lambda 1$-
λm which is then amplified by an optical amplifier 22
which is identified to optical amplifier 14, which then
5   outputs the amplified facility signal on output fiber
24. Wavelengths are not shown as being added/dropped
in the drawing, however, this is understood by those
skilled in the art.

10   In general, even though the optical amplifiers 14 and
22 have a flat gain, the amplitudes of the individual
wavelengths are often different and require adjustment
to attempt to equalize the gain of the respective
channels. This equalization is typically accomplished
15   using VOA's which are inserted in the respective
channels. In addition, the OXC or OADM 18 introduces
losses on the order of 1-5db, which are reflected in
the output power level of the respective channels. If
the output power level in a given channel is below a
20   threshold level, an expensive transponder is required
to raise the power level above the threshold.

Fig. 2 is a block diagram of an optical communication system according to the present invention, in which the output power of each channel is equalized independent of the channel wavelength and input power level. This

5 is accomplished by including an optical amplifier in each channel which is controlled to operate at a predetermined power level, by operating each optical amplifier in a saturation mode. The optical amplifier is termed an "amplet" which is a low-cost optical

10 amplifier using low-cost laser pumps, in comparison to the amplifier and pumps used for amplifying multiple wavelength facility signals.

In Fig. 2, an optical communication system 30 has an

15 optical facility signal comprising multiple channels of different wavelengths input on a single fiber 32 demultiplexed into its constituent wavelengths λ1-λn by a demultiplexer 34, which are then applied to optical amplifiers 36a-36n, respectively in an OXC 37.

20 Although Fig. 3 shows only one input and one output fiber, each bearing n wavelengths, in general there may be more than one such input fiber and one such output fiber and associated demultiplexers and multiplexers,

respectively. The output power level of each of the
optical amplifiers 36a-36n is at a predetermined power
level independent of channel wavelength and input power
level due to those amplifiers also being operated in

5   the saturation mode. This will be described in more
detail later with respect to Figs. 4 and 5. The
respective amplified channel wavelengths are then
applied to the core 38 of the OXC 37, and then the
respective wavelengths are applied from the core 38 to

10   optical amplifiers 40a-40n in OXC 37. The output power
level of each of the optical amplifier 40a-40n are each
at a predetermined power level due to those amplifiers
also being operated in the saturation mode. The
respective amplified channel wavelengths from OXC 37

15   are then multiplexed by multiplexer 44 into a multiple
channel facility signal which is output on a single
fiber 44.

Fig. 3 is a block diagram of a WDM optical communica-

20   tion system in which OLT's 50 and 52 are connected
back-to-back to form an OADM. It is to be appreciated
that there is another OADM (not shown) for optical
signal flow in the opposite direction. Demultiplexer

54 and multiplexer 56 are connected back-to-back via
the channels including optical amplifiers 58, 60 and
62. A multiple channel facility signal is input on a
single fiber 64 and is demultiplexed into its

5   constituent wavelengths λ_1- λ_n Rn by demultiplexer 54.
Wavelengths λ_1, λ_2 and λ_3 are amplified by amplifiers
58, 60 and 62, respectively, and are input to
multiplexer 56. Wavelength λ_4 is amplified by an
optical amplifier 66 and is dropped off at a client

10   equipment 68. Wavelength λ_n is dropped off at a client
equipment 70 without amplification. A client equipment
72 provides a wavelength λ_4 to multiplexer 56 via an
amplifier 74, and a client equipment 76 provides an
unamplified signal λ_m to multiplexer 56. The

15   multiplexer 56 then outputs a multiple channel facility
signal on a single output fiber 78. The client
equipment may be any one of a computer, a SONET
terminal, a telephone switch, a central office switch
for telephones, a digital cross-connect switch, an end

20   device such as a terminal, or the like. Each of the
optical amplifiers 58, 60, 62, 66 and 74 are operated
in the saturation mode so that their respective output
power levels are at a predetermined power level. It is

to be appreciated that the channels to client
equipments 70 and 76 may also include optical
amplifiers.

5   Fig. 4 is a block diagram of a single optical channel
according to the present invention. An individual
wavelength λx is input on a single fiber 82 and passed
by an isolator 84 to a coupler 86 which combines λx
with the light output λp from a laser pump 88. The
10 laser pump 88 has pumping power sufficient to cause
EDFA 90 to operate in the saturation mode so that its
output power level is at a predetermined level. The
amplified optical wavelength λx is then passed by an
isolator 92 to a single output fiber 94.

15
    Fig. 5 is a typical graph of power-in (Pi) versus
power-out (Po) for the optical amplifier 90 of Fig. 4.
It is seen that for an input power level of -30db the
output power level is -15db on the steep part of the
20 curve, and for an input power level of -20db the output
power level is -5db. Thus, it is seen that for a 10db
difference in input power level there is a 10db
difference in output power level, which difference in

power level would have to be subsequently compensated for by a VOA or the use of a transponder in the prior art.

5   In contrast, it is seen that when operating on or near the flat portion of the curve the output power is substantially the same for different input power levels due to operating on the saturation part of the curve. For example, for an input power level of-10db the

10   output power level is - 4db. Thus, it is seen for a 10db difference between input power levels of -20db and -10db there is only a 1db difference between the output power levels of -5db and -4db, respectively. Accordingly, it seen that if amplifiers in different

15   channels are each operating in the saturation mode their respective output power levels will be at a predetermined level which is substantially the same level for each amplifier.

20   This is seen more clearly with respect to Fig. 6 in which four optical channels for four different wavelengths are shown. Each such channel is identical to the channel 80 shown in Fig. 4, with a shared laser

pump 96 providing the same pumping power at λp to each

of the isolators 86a-86d, to operate each of the

optical amplifiers 90a-90d in the saturation mode so

that their respective output power levels are at

5   substantially the same predetermined power level

independent of channel wavelength and input power

level. It is understood that the shared pump 96

provides the same pumping power to each of the couplers

86a-86d via an optical splitter (not shown).

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Fig. 7 is a block diagram of another pump configuration

in which a plurality of optical pumps are coupled to a

plurality of channel amplifiers via a coupler.

Channels 100a-100n include optical amplifiers 102a-

15   102n. Pumping power for the amplifiers 102a-102n are

selectively provided by laser pumps 104a-104m via a MxN

coupler 106 and lines 108a-108n, respectively. The

number of channels is equal to N, and the number of

pumps is equal to M, where M and N are integers, and M

20   is not equal to N.

For example, if there are 32 channels and each channel

requires 20 MW of power, a 4x32 coupler can be used,

with each of the 4 pumps providing 160 MW of power.
Thus, each pump splits power between 8 of the 32
channels.

5   In the configuration shown in Fig. 7, one or more of
the pumps 104a-104m may be a spare pump for use in the
event of another one of the pumps becoming inoperative.

It is understood that there may be a single pump per
10   channel, with the pump power being the same or
different for the respective amplifiers. If the pump
powers are different, it is understood that the
respective amplifiers have different saturation levels.

15   Also, it is understood that there may be multiple
shared pumps used in the practice of the invention.
For example, if there are 32 channels there may be 16
pumps, with 2 channels sharing a pump; or 8 pumps with
4 channels sharing a pump; or 4 pumps with 8 channels
20   sharing a pump, and so on.

Fig. 8 is a block diagram of a plurality of optical
nodes 200a-200l connected in a ring configuration. The

respective optical nodes may comprise OLT's, OADM's, or

the like. An optical signal transmission from one node

to the next is termed a hop. If the optical nodes are

OLT's connected back-to-back according to the prior

5   art, up to five hops may be made without introduction

of a transponder in the lightpath. Thus if an optical

signal were transmitted from node 200a to node 200m, a

transponder would be required at nodes 200f and 200k.

10   In contrast, according to the present invention, due to

the equalization of output power level in the

respective channels in the optical ring, due to

operating the respective channel amplifiers in the

saturation mode, recent modeling results have shown

15   that up to twenty-three hops may be made without

introduction of a transponder in the lightpath.

A further advantage that is derived in such an optical

ring using amplifiers operating at a predetermined

20   output power level in each of the channels, is the

prevention of lasing. Since the power level output of

the amplifiers in the respective channels is

constrained not to rise above a predetermined level, a

given channel's wavelength that traverses the ring

without being dropped can't rob power from another

channel, due to the respective output power levels of

5 the amplifiers being held at the predetermined level.

Accordingly, system cost is reduced, as fewer expensive

transponders are required. Cost of the optical

amplifiers are decreased as less gain is required,

10 VOA's are not required, automatic gain control is not

required and equalization is not required. System

level costs are also decreased as simpler software is

required since no VOA control is required. Further, an

inadvertent ring connection in a given channel will not

15 cause ringing due to the amplifiers in the channel

operating in the saturation mode.

In summary, in the apparatus of the present invention

each channel in an optical communication system

20 includes an optical amplifier which operates in the

saturation mode such that each amplifier has

substantially the same output power level independent

of channel wavelength and input power level.

Although certain embodiments of the invention have been described and illustrated herein, it will be readily apparent to those of ordinary skill in the art that a number of modifications and substitutions can be made to the preferred example methods and apparatus disclosed and described herein without departing from the true spirit and scope of the invention.